The Texas Shrimp Fishery: Analysis of Six Management Alternatives Using the General Bioeconomic Fishery Simulation Model

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Sea Grant College Program
Texas A&M University
College Station, Texas 77843

TAMU-SG-84-202
October 1983

Texas A&M University

Sea Grant College Program

College Station, TX 77843

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ANALYSIS OF SIX MANAGEMENT ALTERNATIVES

USING THE GENERAL BIOECONOMIC FISHERY SIMULATION MODEL (GBFSM)

by

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TAMU-SG-84-202

October 1983

Partially Supported through Institutional Grant NA83AA-D-00061
to Texas A&M University
by the National Sea Grant College Program
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

Price: $3

Order from

Marine Information Service
Sea Grant College Program
Texas A&M University
College Station, Texas 77843

R/F-3
TAMU-SG-84-202
300 October 1983

ABSTRACT

The shrimp fishery of Texas has been the focus of continuing resource management efforts. Six management alternatives, recently proposed in fishery management plans or legislation, are analyzed.

Management alternatives consist of closure of specified areas for particular periods of time, changes in count size regulations, or both.

The analyses were conducted using a computer simulation model General Bioeconomic Fishery Simulation Model designed to represent the important biological and economic processes of the Texas shrimp fishery. For given levels of growth coefficients and natural mortality coefficients the model produced results very close to historical landings in terms of volume, size and seasonal distribution.

Six management alternatives were evaluated in terms of their impact on total landings, amount of discards, cost and returns, and fishing effort employed. Impacts were estimated both for the first year and for a long-run situation, which gave the industry time to adjust by increasing or decreasing the number of bay boats and Gulf vessels.

Management alternatives closing Texas offshore waters in the Fisheries Conservation Zones simultaneously with state closure had a slightly negative impact on total landings in the first year. It was estimated that increased landings later in the year could not offset landings lost due to closure.

The most significant increase in landings resulted from management alternatives including elimination of the count size law. This was reflected in both first-year and long-run equilibria.

Under all management alternatives examined, the number of Gulf vessels increased and the number of bay boats declined. Management alternatives eliminating the size restriction on landed shrimp would have the greatest impact on increasing vessel numbers. Because the industry in 1980 is not in equilibrium, short-run increases in vessel profits associated with these management alternatives would reduce some of the pressure forcing vessels out of the industry.

It was found that closure of inshore waters during the spring season would have a negative impact on total landings the first year and only a small positive impact at equilibrium. At equilibrium, Gulf vessel landings were estimated to increase by 2.65 million pounds (heads-off) annually, with bay landings being reduced by 2.50 million pounds.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

INTRODUCTION

The Gulf of Mexico fishery is the most important fishery in the United States in terms of value of catch, and shrimp is the most important component of the Gulf fishery. Of the total 1978 shrimp catch, Gulf fishermen landed 248 million pounds (58.6 percent of the U.S. total) valued at $319.6 million, or 82.9 percent of the U.S. total (U.S. Department of Commerce, 1979). Commercial landings of fish and shellfish represent a substantial segment of the Texas economy (Cobb, 1970) and were valued at about $148.9 million in 1978. Shrimp is the most valuable component of the Texas fishing industry. In 1978, shrimp landings ($141 million) represented about 95 percent by value of all fish and shellfish landings in Texas (U.S. Department of Commerce, 1979).

The shrimp fishery of Texas can be divided into two major categories, Gulf and bay. Gulf vessels are larger and more powerful. They stay out of port several days to several weeks at a time and have greater facilities for storage of fuel, supplies, ice and catch. These vessels unload at dockside after a fishing trip. The shrimp usually are unloaded heads-off and packed in ice. By-catch is discarded at sea. The main season for Gulf vessels is from late spring through early or mid-winter, although some Gulf shrimp are taken throughout the year if weather and economic conditions are suitable.

Bay boats are smaller and less powerful than Gulf vessels and return daily to the docks to unload their catch, which is usually made up of smaller shrimp unloaded fresh (heads-off). These bay boats trawl the several major bay systems on the Texas coast and ocassionally work Gulf waters adjacent to the bays. In Texas there is a spring bay season for shrimping from about May 15 to July 15, and a four-month fall season beginning about August 15 (Christmas and Etzold, 1979).

Probably the most important aspect of the bay shrimp fishery relates to the function of the bays in the life cycle of shrimp. The relatively shallow and protected waters of the major bay systems serve as nursery areas during early stages of shrimp growth. As the shrimp mature, they move from the bays to the offshore waters of the Gulf. Hence, during bay shrimping seasons, practically all shrimp are subjected to the harvest efforts of the bay fleet before they arrive offshore and become susceptible to Gulf vessels. Generally, shrimp caught in the bays during spring and summer are younger and, therefore, smaller, than shrimp caught offshore.

The purposes of this paper are to simulate the major biological and economic variables in the fishery and to evaluate the effects of alternate public and private management choices on the industry. Because the bay fishery is ecologically coupled to the Gulf shrimp fishery, the simulation includes both fisheries. However, throughout the analysis, emphasis is placed on examining results relative to the bay fishery. The following management alternatives are evaluated:

1. Close Texas offshore waters during June and July;
2. Close Texas offshore waters during June and first two weeks in July;
3. Eliminate size restrictions in bay and Gulf waters;
4. Combine 1 and 3 above;
5. Combine 2 and 3 above; and
6. Close the spring bay season, May 15-July 15.

The first five management alternatives above are related to measure 2 in the Shrimp Management Plan whose objective is to "Establish a cooperative closure of the territorial Sea of Texas and the adjacent U.S. Fisheries Conservative Zone (FCZ) during the time when a substantial portion of the brown shrimp in these waters weigh less than a count of 65 tails to the pound."* The rationale for this measure is "... to increase the yield of shrimp and to eliminate waste by discard of undersized brown shrimp in the FCZ. Data indicate that closure would protect the shrimp until they have generally reached a more valuable size. Estimation of the count restriction would allow all the shrimp that are caught to be landed*" (Center for Welland Resources, 1979). In this analysis it is assumed that when the offshore area is closed it will be closed to all shrimping from the shoreline to 200 miles offshore. The sixth management alternative was proposed in House Bill No. 582 submitted to the 1978 Texas Legislature. The rationale for closing the spring bay season is to protect the small brown shrimp, enabling them to attain a larger size before being harvested.

MODEL METHODOLOGY AND DATA DESCRIPTION

Purpose and Form

This model is designed to represent in a simplified form the major biological and economic aspects of the shrimp fishery in Texas. As a management-oriented model, its purpose is to provide a framework to allow prediction and analysis of the effects on the fishery of changes in key biological and economic parameters. The model may be used to generate statistics on landings and revenues for given periods and levels of fishing effort, aiding resource planners in forecasting effects of potential policy changes in the fishery.

A simplified representation of the key biological and economic aspects of the Texas shrimp fishery is presented in Figure 1. The biological submodel represents recruitment, offshore movement, growth, natural mortality and fishing mortality (harvest) of both brown and white shrimp.

Recruitment of each species in the bays is a function of environmental factors and is treated as external to the model. Shrimp movements into and out of Texas waters were assumed to offset each other, but data are not available to support this assumption.

Treating initial recruitment for the two species as driving variables, individual shrimp enter the simulation model after they are recruited into the bays. Once they have entered the model, shrimp grow, migrate to Gulf waters and are subjected to natural and fishing mortality in the bays and the Gulf. Fishing mortality is a function of the level of fishing effort to which shrimp in an area are subjected, determined by economic and regulatory factors.

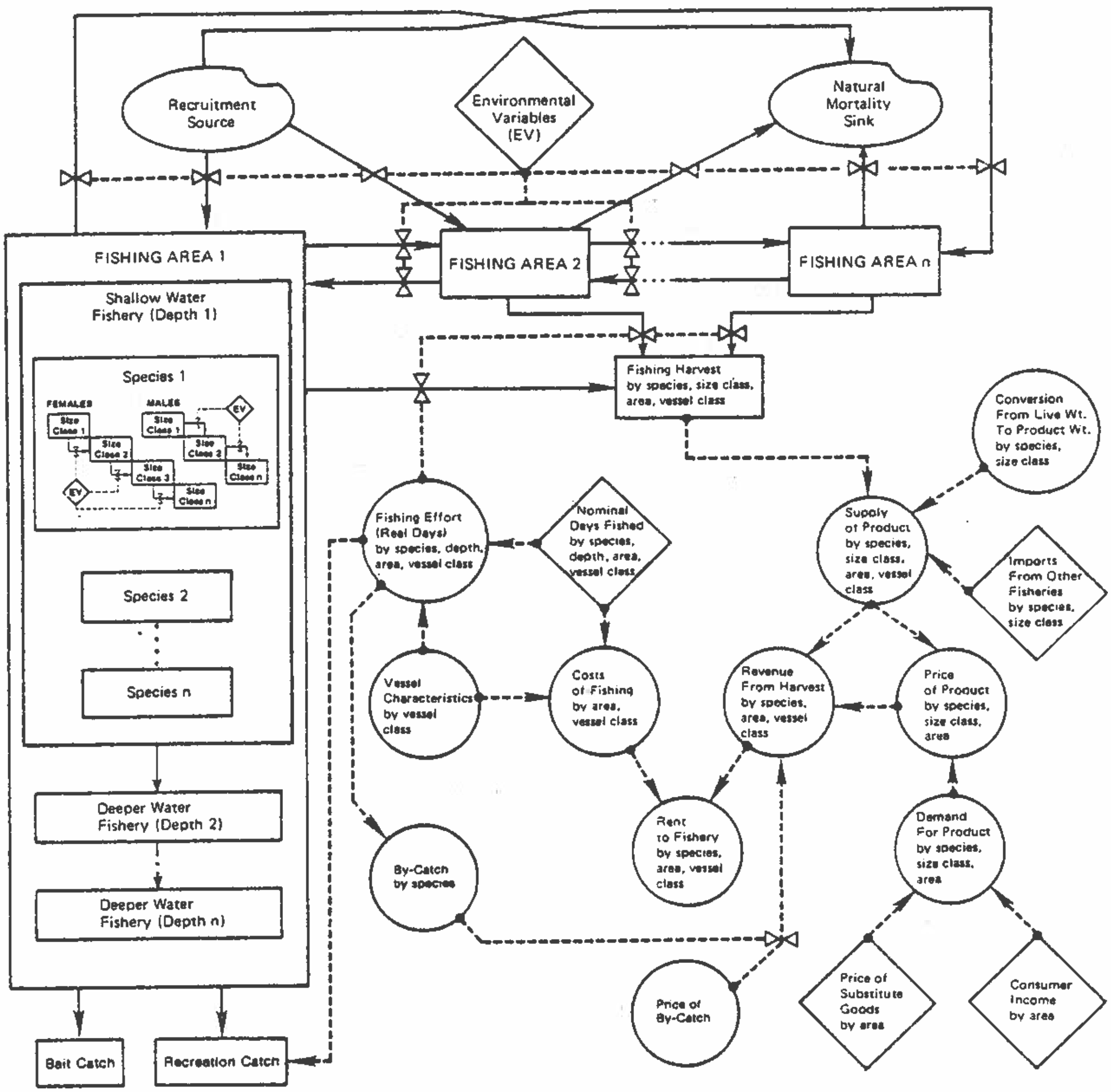


Figure 1. Conceptual Diagram of General Bioeconomic Fisheries Simulation Model.

Model Description

The model used to simulate the Texas brown and white shrimp industry is essentially an adaptation of a model already developed at Texas A&M University and described by Isakson, Grant and Griffin (1980). The model is called the General Bioeconomic Fisheries Simulation Model (GBFSM).

In this analysis the GBFSM is applied for a two-species shrimp fishery harvested by two groups operating essentially in distinct fishing areas. One group is constrained by severe seasonal and catch limitations. The 52-week time step was used because seasonal regulations to the bay fishery can be simulated with satisfactory accuracy. This analysis is made depth-specific, with bay fleet harvest and Gulf fleet harvest differentiated. The analysis includes all four of the National Marine Fisheries Services statistical reporting areas (areas 18-21) comprising Texas waters.

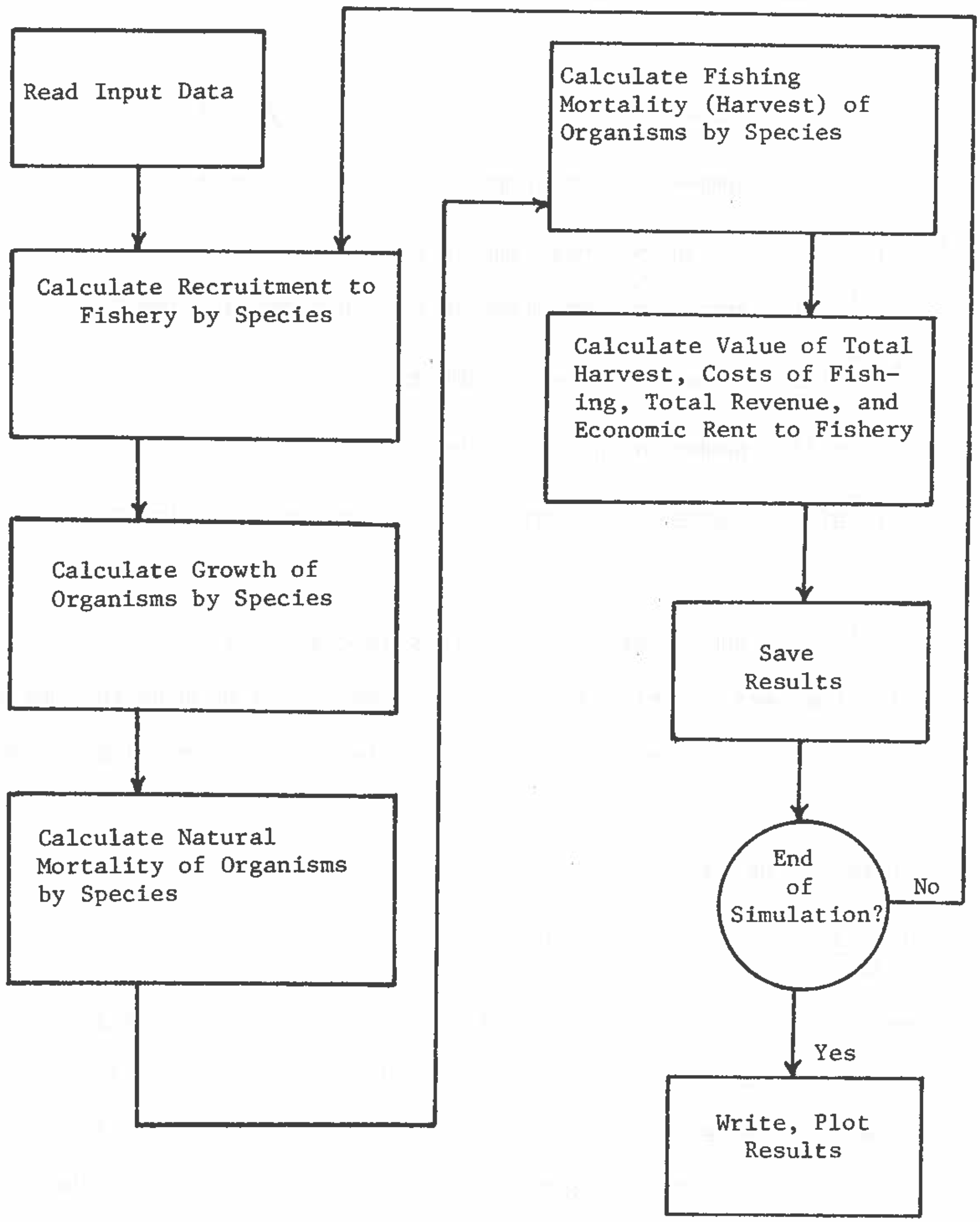
Figure 2 is a flow chart of the simulation model structure. The model is a set of non-linear difference equations in FORTRAN that represent the dynamics of the system. The difference equations are solved and the state of the system is updated for each week of simulated time. The state of the system at a specific time refers to the values calculated by the model for the system variables at that point in time.

The basic equations for simulating system dynamics can be represented as follows:

$$(1)\quad X_{hijt+1} = X_{hijt} + \frac{\Delta X_{hij}}{\Delta t}$$

[for h = 1 to 4; i = 1, 2; j = 1 to 4; t = 0 to 12]

where X_{hijt+1} = number of organisms in compartment h, species i, size class j, present at time t + 1;



Source: Adapted from Griffin, Warren, and Grant.

$\frac{\Delta X_{hij}}{\Delta t}$ = net change in number of organisms in compartment h, species i, size class j, over the time interval t to t + 1;

$\Sigma_i \Sigma_j X_{1ijt}$ = number of organisms in bay fishery at time t;

$\Sigma_i \Sigma_j X_{2ijt}$ = number of organisms in bay harvest at time t;

$\Sigma_i \Sigma_j X_{3ijt}$ = number of organisms in Gulf fishery at time t;

$\Sigma_i \Sigma_j X_{4ijt}$ = number of organisms in Gulf harvest at time t;

$\Sigma_h \Sigma_j X_{h1jt}$ = number of brown shrimp at time t;

$\Sigma_h \Sigma_j X_{h2jt}$ = number of white shrimp at time t;

$\Sigma_h \Sigma_i X_{hi1t}$ = number of organisms in size class 1 at time t;

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$\Sigma_h \Sigma_i X_{hi4t}$ = number of organisms in size class 4 at time t.

During the rest of this discussion reference will be made to time period if appropriate, but subscripting every variable with t is eliminated for simplicity.

Changes in the bay fishery biomass over time can be expressed as:

$$(2)\quad \frac{\Delta X_{1ij}}{\Delta t} = R_{ij} - NM_{1ij} - FM_{1ij}$$

Where R_{ij} = number of individuals of species i, size class j, recruited into the bays during the time interval;

NM_{1ij} = number of individuals of species i, size class j, dying due to natural (non-fishing) mortality in the bays during the time interval;

FM_{1ij} = number of individuals of species i, size class j, removed by fishing in the bays during the time interval.

Recruitment of organisms into the bays varies seasonally and is differentiated by species.

(3) $R_{ij} = RMAX_i \cdot (S_i)$

where $RMAX_i$ = maximum number of individuals of species i that can be recruited into the fishery during one time interval;

S_i = a seasonality factor, $0 \leq S_i \leq 1$, representing the relative magnitude of recruitment of species i into the fishery during a given time interval.

Brown shrimp recruitment peaks in March and April, with somewhat smaller maxima in June and September; it is least in December and January. White shrimp recruitment increases during spring to a peak in June and July, then decreases slowly to very small levels in December, January and early February (Griffin, Cross, and Ryan, 1974).

Changes over time in the Gulf fishery biomass can be expressed as:

(4) $\frac{\Delta X_{3ij}}{\Delta t} = I_{ij} - NM_{3ij} - FM_{3ij}$

where I_{ij} = number of individuals of species i, size class j, immigrating to the Gulf from bays during the time interval;

NM_{3ij} = number of individuals of species i, size class j, dying due to natural (non-fishing) mortality in the Gulf during the time interval;

FM_{3ij} = number of individuals of species i, size class j, removed by fishing in the Gulf during the time interval.

(5) $I_{ij} = IMM_{ij} \cdot (X_{ij})$

where IMM_{ij} = the proportion of the bay population of species i, size class i, immigrating to the Gulf from bays during the time interval.

Natural mortality is represented in the model on a species-specific basis as a constant rate per time period. It is assumed to be unrelated to size class.

(6) $NM_{hij} = NMORT_i \cdot (X_{hij})$ ... [for h = 1 or 3]

where $NMORT_i$ - the proportion of the bay or Gulf population of species i dying due to natural causes during the time interval.

For this study, a weekly instantaneous natural mortality rate of 0.08 is used for both brown and white shrimp.

Growth of organisms is represented on a species-specific basis by the von Bertalanffy equation:

(9) $GRO_i = K_i L_{\infty i} \cdot e - I_i W_i$

where GRO_i = growth of species i shrimp in mm/week;

K_i = the weekly rate at which species i shrimp grow;

$L_{\infty i}$ = the terminal or asymptotic length to which species i shrimp grow, 182 and 194 for brown and white shrimp, respectively (Christmas and Etzold, 1979),

e = 2,7128, base of natural logarithms;

W_i = number of weeks over which species i shrimp age.

The specific coefficients used for brown and white shrimp in equation (9), and the length-weight relationship used to convert number of organisms in the harvest to pounds were taken from data reported by Christmas and Etzold (1979).

The economic component of the model is linked to the biological sub-model through fishing effort and harvest (landings). The level of fishing effort is determined external to the model, as discussed below in the section on economic data, and is treated as a driving variable. Prices can be determined internally in the model using price flexibility equations. The Price flexibility equation is:

$$P_{jt} = \bar{P}_{jt}[1.0 - F_{jt} \frac{\bar{P}_{jt} (\bar{X}_{jt} - X_{jt})}{\bar{X}_{jt}}]$$

where P_{jt} = the price of size class j;

P_{jt} = the mean price of size class j;

X_{jt} = the estimated landings of size class j;

$\bar{X}_{jt}$ = the landings of size class j at time t.

In this analysis, however, shrimp are considered external to the model, are developed from 1977 NMFS data by shrimp size class and by time period, and are species-specific. Unit costs of fishing are developed and defined as the sum of variable and fixed costs per vessel per time period. Variable cost for a given vessel class is the product of variable cost per day fished, number of nominal days fished per vessel, and number or vessels in that class.

Fishing mortality (harvest) is a function of the level of fishing effort in real days fished, the susceptibility of organisms to harvest, and the abundance or organisms. Hence the two compartments describing harvest can be represented as:

(7) $FM_{hij} = (FE) . (HC_i) . (X_{h-1ij})$ ... [for h = 2 or 4]

where FE = fishing effort in real days fished expended in the fishery (bay or Gulf) during the time interval;

HC_i = proportion of bay or Gulf population of species i that is removed by one real day fished.

Calculation of fishing effort in terms of real days fished reflects an adjustment of reported (or nominal) days fished to account for differences in fishing power between various vessel classes. Hence, fishing effort is calculated as a product of relative fishing power of class k vessels and number of nominal days fished by class k vessels. Relative fishing power is expressed as a ratio of catch per nominal day fished by class k vessels to that of a standard class vessel.

(8) $FE_k = (NDF_k)\ (NVES_k)\ (RFP_k)$ ... [for h = 2 or 4; k = 1 to 2]

where NDF_k = number of nominal days fished in bays or Gulf by the "average" type k vessel during the time interval;

$NVES_k$ = number of type k vessels in the bay or Gulf fishery during the time interval;

RFP_k = relative fishing power of type k vessels, which is calculated as the ratio of catch per nominal day fished by a vessel in class k to that of a standard (k = 2) vessel.

(10) $VC_k = VDF_k \cdot NDF_k \cdot NVES_k$

where VC_k = variable cost of all vessels of class k;

where VDF_k = variable cost per nominal day fished per vessel of class k.

Fixed cost for a class of vessel is the product of the fixed cost per vessel and the number of vessels.

(11) $FC_k = FV_k \cdot NVES_k$

where FC_k = fixed cost of the class k vessels;

FV_k = fixed cost per vessel of class k.

Total cost for a given vessel class (TC_k) equals the sum of variable and fixed costs.

(12) $TC_k = VC_k + FC_k$

Revenues are a function of price and landings. For a given vessel class k total revenue equals the product of shrimp price and quantity harvested (by size class and species).

(13) $TR_k = \sum_{ij} (P_{ij} \cdot WT_{ijk})$

where TR_k = total revenue for vessel class k;

P_{ij} = price of shrimp of species i, class j;

WT_{ijk} = pounds of shrimp of species i, class j, landed by vessels in class k;

Rent captured by a given vessel class in the fishery is represented as the difference between total revenue and total cost.

(14) $RENT_k = TR_k - TC_k$

where $RENT_k$ = economic rents (excess profits) captured by vessel class k.

Model Validation

To develop a validation procedure for examining the model's predictive capabilities, a set of observations was generated against which to compare predicted values. NMFS brown and white shrimp landings data were used. Shrimp landings, effort and value are reported monthly by species and size for every NMFS statistical area. Data from 1963 through 1974 (except 1967) were combined over the four statistical areas corresponding to Texas waters. Average effort and landings by species and size class were then calculated by vessel class and fishing depth (inshore and offshore) for each month. The model is tuned to these averages. Results predicted by GBFSM are compared with the NMFS data. The model's ability to predict landings at various effort levels is also tested through comparisons with NMFS data.

Data Description

Data requirements for the simulation model are met almost entirely from secondary sources. Landings data are from data tapes supplied by NMFS and include landings from Texas waters. Table 1 lists key parameters and data inputs, with dimensions in parentheses. Regarding the biological parameters, sufficient information for model purposes is available in published sources. Most biological parameter values are open to dispute, and many are reported as a range of values.

For key biological parameters, input data may be described as follows. Phenology factor E represents time-dependent recruitment rates. These are entered by month for each species and reflect seasonal trends in recruitment. The coefficient ICOF is a maximum monthly introduction rate for young shrimp and is entered by species. To arrive at recruitment for a given species and month, the model multiplies ICOF by the appropriate E value. The introductory coefficient represents a variable for which accurate estimates do not exist. In the initial phases of model tuning, ICOF is used to some extent as a tuning variable. In later stochastic applications of the model, ICOF is the stochastisized variable.

Boundaries between size classes are entered by species in mm of length

Table 1. Identification and Definition of Model Input Parameters, in Order of Entry to GBFSM, with Dimensions where appropriate.

Parameters	Definition	Dimensions
NA	Number of areas	
NC	Number of cohorts	
NSP	Number of species	
ND	Number of depths	
NVC	Number of vessel classes	
NSC	Number of shrimp size classes	
NM	Number of time periods	
NER	Time divisions, phenology factor E	
NPH	Time divisions, phenology factor GRT	
NBC	Number of species of by-catch	
NSX	Number of sexes of shrimp	
TIME	Number of time periods per run	
CCT	Number of time steps per cohort	
CN	Timing coefficient, NM	
CER	Timing coefficient, NER	
CPH	Timing coefficient, NPH	
C8	Minimum numbers for a cohort	
ICOF	Gross recruitment rate	(NSP, NA)
ISZ	Initial size for recruitment	(NSP, NSX)
SZCOF	Minimum size shrimp begin to move	(NSP, NSX)
E	Time-dependent rate in recruitment	(NSP, NER)
ER	Movement rates (among depth, areas)	(NSP, ND, NA, NA)
COL	Labels for time periods	(NM)
GCOF	Growth coefficient	(NSP, NSX)
MSZC	Maximum size for growth	(NSP, NSX)
GRT	Time factors altering growth	(NSP, NPH)
C3	Linear coefficient, length/wt. equation	(NSP)
C4	Power coefficient, length/wt. equation	(NSP)
NMOCF	Natural mortality rates	(NSP, ND, NSC)
BMESH	Secondary harvest lower size limit	
RMESH	Auxiliary harvest lower size limit	

Table 1 (Cont'd.)

Parameter	Definition	Dimensions
BC	Secondary harvest coefficient	
RC	Auxiliary harvest coefficient	
ETM	Conversion ratio for units in catch	
C5	Upper size limit	
C6	Lower size limit	
C7	Altered mortality factor	
CMESH	Primary harvest lower size limit	(NSP, ND)
CF	Percentage of culls in legal catch	(NVC, ND)
SL	Boundaries between size classes	(NSP, NSC)
FMAX	Density factor, fishing mortality	(NA, ND, NA)
VKIL	Minimum size limit	(NSP, ND, NM)
PERF	Factor determining by-catch	(NBC, NVC, NM)
FRL	Footrope length (net size)	(NVC)
HP	Horsepower (engine size)	(NVC)
C1	Power coefficient on HP	(NSP)
C2	Power coefficient on FRL	(NSP)
CONV	Heads-on to heads-off conversion	(NSP)
NV	Number of vessel classes	
C	Crew number per vessel	(NVC)
FC	Fixed cost by vessel classes	(NVC)
CVC	Crew's variable cost per nominal day fished	(NVC)
OCO	Owner's opportunity cost	(NVC)
OCC	Crew's opportunity cost	(NVC)
PC	Packing charges	(NVC)
SHARE	Crews' percentage of landings	(NVC)
COST	Fishing cost per effort unit	(NVC, ND)
PMCSP	Fish (shrimp) prices	(NSP, NSC, NM)
PCATCH	Unit price received for by-catch	(NBC)
YR	Coefficient, gross effort adjustment	
IX	Random number "seeds"	
SP	Statistical parameter	
DFN	Nominal days fished (effort)	(NSP, NA, ND, NVC, NM)
ADSVM	Actual data (landings	(NS, NSP, ND, NSC, NVC, NM)

Source: Adapted from Isakson, Grant, and Griffin (pp. 3-6).

as the parameter SL. VKIL provides a basis for manipulating minimum size limits by species, depth and month.

Like phenology factors E, above, phenology factors GRT are also entered by species and month but reflect seasonal trends (if any) in growth rates. The species-specific growth coefficients are multiplied by appropriate GRT values to derive growth rates for each month. The weekly growth ratio coefficients are .075 and .077 for brown and white shrimp, respectively (Christmas and Etzold, 1979, p. 7).

The natural mortality rate NMCOF is multiplied by shrimp population each week during the simulation to derive natural mortality. Christmas and Etzold, 1979, (p. 7) report a wide renge of values for weekly instantaneous natural mortality rates for brown and white shrimp, ranging from o.02 to 0.46. It was assumed in this study that smaller shrimp have a higher natural mortality rate than larger shrimp. Table 2 shows the natural mortality rates used in this study. Natural mortality rate was fixed at 0.16

Table 2. Natural Mortality per week by Heads-off count per pound.

Species	Size 1 Under - 20 Count	Size 2 21 to 30 Count	Size 3 31 to 50 Count	Size 4 51 - 67 Count	Size 5 68 - over Count
Brown	.08	.08	.09	.12	.16
White	.10	.10	.12	.14	.16

for size class 5 and smaller shrimp and then allowed to increase to lower levels for the larger shrimp as tuning the model dictated (see next section). Results are presented in Tables 1a through 5a in Appendix A for holding natural mortality rate of size 5 at 0.09, 0.12, 0.16 and 0.20, respectively.

The density factor FMAX is another important model parameter. It is entered by fishing area and reflects relative density of shrimp in inshore and offshore waters, thereby directly affecting catch per unit of fishing effort. Estimation of density factors is not as well-developed science. In view of the inexact nature of density factors, and model responsiveness to them in the inshore/offshore prediction of landings, FMAX has become an important tool in tuning the model to actual conditions.

The economic data have a variety of secondary and primary sources. Bay boats are defined in the model as non-Coast-Guard-registered vessels plus Coast-Guard-registered vessels that make at least 25 percent of their trips into the inshore waters to shrimp. Gulf "vessels" are defined as other Coast-Guard-registered vessels. In this model, it is assumed that the bay fleet operates in the bays and near offshore waters, and that the Gulf fleet operates exclusively offshore.

The Texas fleet fish both Texas and adjacent waters. Since the analysis is only concerned with Texas waters, the number of vessels were adjusted to full-time-equivalent required to harvest the Texas resource under current operating conditions. The number of full-time equivalent bay and Gulf vessels using the shrimp resource in Texas waters was calculated as follows: The total number of days fished in Texas waters plus the total number of days fished in waters outside of the Texas but the shrimp that were landed in Texas were assumed to be the total days fished by the Texas fleet. Bay boat-days fished were 15,039 and Gulf vessel-days fished were 72,288. Assuming that in one year a full-time bay boat spends 30 days fishing and full time Gulf vessels spend 62 days fishing then the number of full-time equivalent bay boats is 500 and Gulf vessels is 1169.

Specific economic parameters include vessels descriptive data used in deriving relative fishing power. Length of foot rope of the trawl net (FRL) and engine horsepower (HP) are entered as averages for each vessel class.

Unit costs of fishing are entered into GBFSM as the variables COST, FC, CVC, OCO and OCC by fishing vessel (which is analagous to a division by vessel class for this model). The variable cost per day fished per boat was estimated to be $419 and $915 for bay boats and Gulf vessles, respectively, in 1979 dollars. Fixed costs were adjusted for days fished in non-Texas waters and were $7,602 for bay boats and $30,983 for Gulf vessels. Opportunity costs for bay boat and Gulf vessel owner/operator were assumed to be $10,541 and $13,442, respectively. Opportunity costs for crew were assumed to be $7,621 and $10,701 for bay boats and Gulf vessels, respectively. Opportunity costs were set such that, for the baseline zero, rents occur to owners and crews. Fishing effort, in nominal days fished, is input as the variable DFN, by species, depth, vessel class and month. Effort is estimated based on average values calculated from 1963-74 NMFS data.

Shrimp prices are a key input (PMCSP) and are developed by shrimp size class for each month for NMFS data for the base year. Prices are also entered by species.

For tuning and comparative purposes, NMFS landings data for the years 1963 through 1974 are used. These data are entered as the variable ADSVM by species, size class, and bay or Gulf catch.

RESULTS

Research results take several forms. Initially, the bioeconomic model was tuned to average 1963-1974 conditions in the Texas shrimp fishery. The results of this initial simulation exercise forms the basis for validation and sensitivity analysis of the model and for generating the baseline conditions through which management alternatives are simulated and compared.

Tuning The Model

Initial adjustment of the model was undertaken to achieve a satisfactory simulation of an average of 1963-1974 (excluding 1967) performance in the Texas shrimp fishery. A brief summary of the results of this tuning exercise is presented in Table 3, in which landings values, predicted by the model, by species, vessel class and shrimp size class are compared to average values from NMFS data. In this basic simulation mode, the model approximates actual values very well.

Seasonality in the shrimp fishery is very important in terms of evaluating management alternatives because five of the six suggested alternatives include seasonal closures. The model was tuned to monthly variations in landings within each species, vessel class and size class category. In the monthly adjustments, no effort was made to duplicate exactly the actual landings each month for each category, but relative magnitudes and variations between months in the data were approximated by the simulation. Figure 3 shows that predicted and actual monthly landings for brown and white

Table 3. Results of Basic Model Simulation of Average Shrimp Fishery Conditions, Texas, 1963-1974. Weights are in thousands of pounds.

Category	Landings by Shrimp Size Class				
	1	2	3	4	5
Brown Shrimp					
Inshore					
Predictions	0.0	1.5	58.3	92.2	1,096.8
Actual data		0.7	29.6	145.6	1,066.6
Offshore					
Predictions	3,031.4	9,318.7	12,386.4	1,859.8	410.5
Actual data	4,035.1	9,121.0	11,593.5	1,939.7	190.7
White Shrimp					
Inshore					
Predictions	190.4	753.9	1,615.3	1,208.7	717.8
Actual data	117.7	962.6	1,654.9	973.8	782.5
Offshore					
Predictions	1,509.6	1,636.2	1,459.8	520.9	27.1
Actual data	1,423.7	1,898.4	1,443.1	279.8	124.0

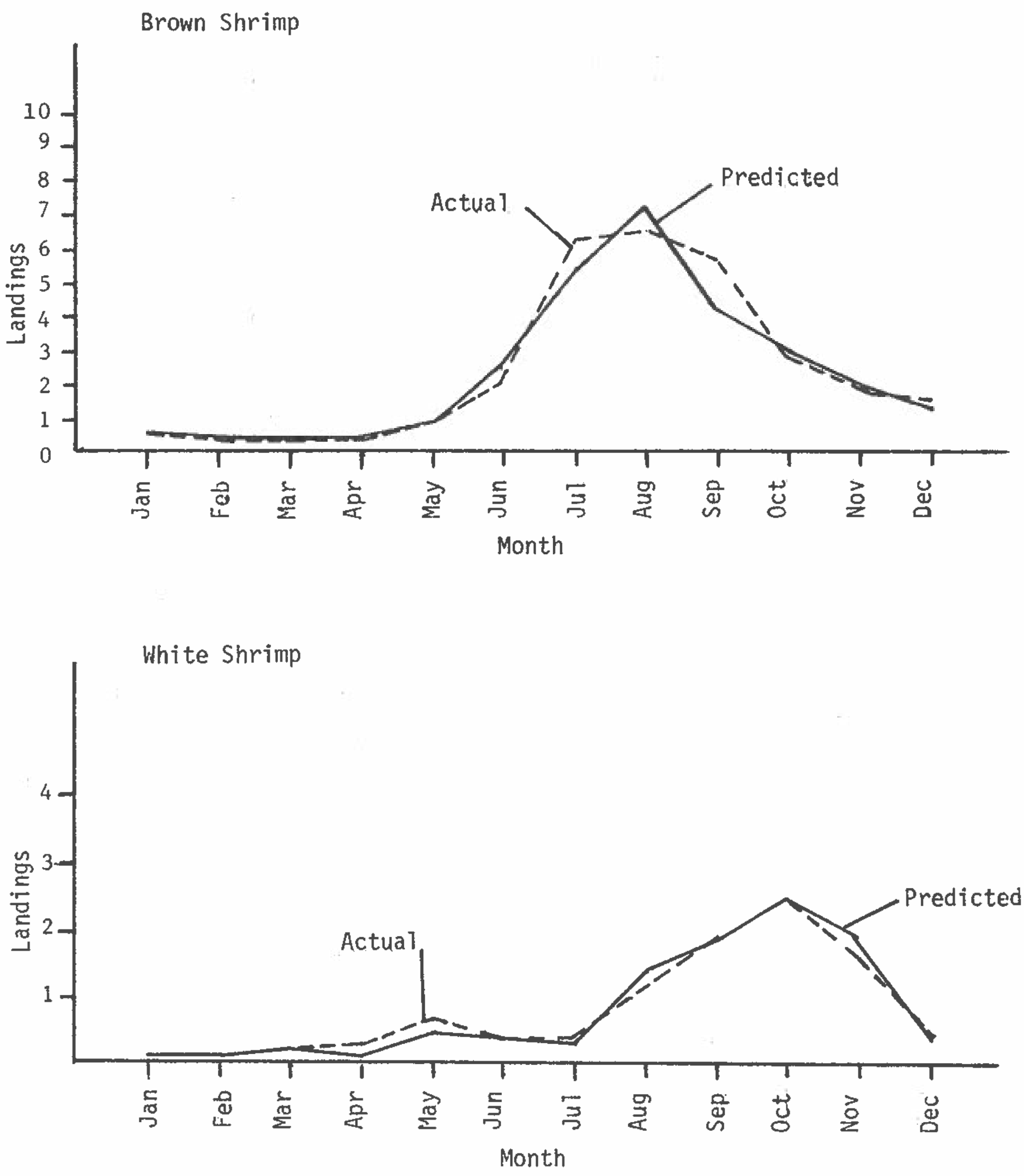

Figure 3. Actual and Predicted Landings of Brown and White Shrimp by Month, Texas, 1963-1974 Average. Landings are in Millions of Pounds.

shrimp are not substantially different.

Baseline Simulation

A baseline version of the model was developed against which to test the impact of changes in fishery management. To reflect more recent fishing patterns, averages of the last five years for which adequate data are available (1970-1974) were used to generate the baseline. (Days fished by boat and vessel, species, inshore/offshore and months are presented in Table 1B in Appendix B). The new count laws that became effective Sept. 1, 1980 are incorporated (shrimp must "count" no more than 50 tails per pound from August 15 through October 31, with no count regulations in November and December). For any policy analysis, changes that occur when a policy is implemented are the main concern, so the base model is forced into economic equilibrium under assumptions that the fishery is an open-access, common property resource. This is accomplished by adjusting the opportunity cost of the owner/operator's labor and crew. Because the model uses 1979 dollars, very little adjustment was necessary. Baseline simulation results are presented in Table 4. Baseline estimated catch is presented by inshore/offshore, species, size class and month in Tables 2b through 5b in Appendix B.

Landings of heads-off shrimp (tails) by bay boats are estimated to be 6.81 million pounds, while Gulf vessels land 32.13 million pounds, giving consumers 38.91 million pounds of shrimp from Texas waters. Because equilibrium is assumed, excess profits are zero. Fishing craft are reported in

Table 4. Baseline Conditions as Estimated by GBFSM for Texas Shrimp Fishery.

Item or Group	Model Predictions
Landings (Heads-off)	
Boats (Mil lbs)	6.81
Vessels (Mil lbs)	32.13
Total (Mil lbs)	38.94
Estimated Culls (Heads-off)	
Boats (Mil lbs)	0.02
Vessels (Mil lbs)	6.58
Excess Profits	
Boat Owners (Mil $)	0.00
Vessel Owners (Mil $)	0.00
Boat Crew (Mil $)	0.00
Vessel Crew (Mil $)	0.00
Number Full Time Equivalent Craft	
Boats	500
Vessels	1,169
Days Fished	
Boats	14,731
Vessels	52,614

number of full-time-equivalent craft. Fleet size was estimated at 500 boats and 1,169 vessels. Although the number of craft is determined external to the model, the change in the fleet size is estimated using GBFSM for different policy analyses.

Culls estimated by GBFSM are 0.02 and 6.58 million pounds for bay boats and Gulf vessels, respectively. Bay boats are assumed to keep 90 percent of undersized shrimp, while Gulf vessels are assumed to keep only 5 percent. Brown shrimp discards of the May-August catch off Texas average 33 percent by number (Berry and Benton, 1969; Baxter, 1973). The percentages of culls by month estimated by GBFSM are shown in Table 5. For May-August GBFSM estimates culls to be 29 percent of total catch. This is a slight underestimate relative to results of the studies mentioned. In Table 6 the percentage distribution of culls throughout the year compare vary favorably with actual brown shrimp landings of size class 5 from offshore waters (if actual culling practices are constant through the year as GBFSM assumes).

Bay boats fished an average of 14,731 days and Gulf vessels fished 52,614 days in 1970-1974 (Table 4). A day fished is considered to be 24 hours of actual fishing time.

Management Alternative Analyses

Six management alternatives for the Texas shrimp fishery have been suggested and discussed (page 3). Issues relating to shrimp seasonality and growth are important considerations in policy analysis for the industry

Table 5. Estimated Offshore Landings and Culls of Brown Shrimp (Mil lbs) Using 1970-1974 Average Days Fished in GBFSM.

Month	Total Landings	Culls	Total Landings plus Culls	% Culls
Jan.	0.57	0.03	0.61	5
Feb.	0.39	0.02	0.41	5
Mar.	0.40	0.05	0.45	12
Apr.	0.44	0.14	0.58	24
May	0.77	0.30	1.06	28
Jun.	1.84	0.86	2.70	32
Jul.	4.95	1.42	6.37	22
Aug.	7.03	1.67	8.71	19
Sep.	4.28	0.96	5.24	18
Oct.	3.00	0.44	3.44	13
Nov.	2.04	0.23	2.27	10
Dec.	1.31	0.12	1.42	8
Total	27.01	6.26	33.27	19

Table 6. Comparison of Percentage Distribution by Months of Size Class 5 of Actual Brown Shrimp Landed from Offshore Texas Waters and Estimated Culls.

Month	Actual 1970-74 Average Size Class 5		Estimated Culls
	Vessels and Boats	Vessels Only	
	Percent		
Jan.	1.3	1.5	.5
Feb.	1.0	1.2	.3
Mar.	1.1	1.3	.8
Apr.	1.1	1.3	2.3
May	3.8	3.5	4.7
Jun.	17.3	10.0	13.8
Jul.	23.1	23.8	22.7
Aug.	21.2	23.7	26.8
Sep.	13.5	15.1	15.4
Oct.	7.6	8.6	7.1
Nov.	5.2	5.9	3.7
Dec.	3.7	4.2	1.9
Total	100.0	100.0	100.0

and are basic to the rationale for closures and removal of size limits. Several assumptions must be discussed before the results are analyzed.

Excess profits (or losses) cannot be maintained in the fishery because the shrimp fishery is an open-access, common property resource. If excess profits exist, additional capital and labor <u>will</u> move in, dissolving those excess profits. It is assumed that days fished will be increased by increasing the number of vessels (hold days fished per vessel constant). It is also assumed that the adjustment will take place in equal increments. When additional capital and labor move into the fishery, they do so rapidly. However, when losses are incurred, capital and labor move out slowly because of asset fixity (Hathaway, 1963). Past observation of expansion in the shrimp fishery and the useful life of a vessel indicates that three to five years under excess profits are required to achieve a new equilibrium, and that with losses eight to twelve years must pass before equilibrium is reached.

Finally, it is assumed that fishing craft and fishermen will remain idle during the seasonal closure except for when they shrimp outside of Texas waters. Bay boats fish only in Texas waters and do not have alternate fisheries. Bay oystering is a closed season, and the finfish industry in Texas would not support the fishing capacity of the fleet of bay shrimp boats. NMFS catch data show that Texas Gulf vessels take between 11 to 19 percent of their catch in Louisiana offshore waters. Although this activity may increase somewhat, it is assumed to remain constant for simplicity of analysis and because the Louisiana offshore waters will not support the entire Texas fleet during the two-month Texas closure.

First-year impacts are shown in Table 7, and long-run impacts showing

Table 7. First Year Impact of Management Alternatives for Texas Shrimp Fishery.

Item or Group Affected	Management Alternative[1]							
	1	1a	2	2a	3	4	5	6
1. Change in days fished								
Boats	-488	-488	-364	-364	0	-488	-364	-3,436
Vessels	-11,351	-7,225	-7,823	-3,344	0	-11,351	-7,225	-15
2. Change in landings								
Boats (mil lbs)	-0.18	-0.19	-0.12	-0.13	0.02	-0.16	-0.10	-1.66
Vessels (mil lbs)	-3.28	-1.41	-1.86	0.02	6.58	1.01	3.10	0.89
Total effect on available supply (mil lbs)	-3.46	-1.60	-1.98	-0.11	6.60	0.85	3.00	-0.87
3. Change in estimated culls								
Boats (mil lbs)	0.00	0.00	0.00	0.00	-0.02	-0.02	-0.02	0.00
Vessels (mil lbs)	-2.29	-1.89	-1.63	-1.17	-6.58	-6.58	-6.58	0.12
4. Change in excess profits								
Boat Owners (mil $)	-0.28	-0.32	-0.16	-0.21	0.05	-0.24	-0.12	-0.69
Vessel Owners (mil $)	2.29	4.20	2.55	4.01	9.78	9.14	10.28	2.68
Boat Crew (mil $)	-0.12	-0.13	-0.08	-0.09	0.01	-0.11	-0.07	-0.53
Vessel Crew (mil $)	-2.01	-0.60	-1.15	0.25	2.44	-0.31	0.78	0.66

1)
1. Close Texas offshore June and July.
1a. Close Texas offshore June and July with 10% increase in days fished per vessel during rest of year.
2. Close Texas offshore June and first two weeks in July.
2a. Close Texas offshore June and first two weeks in July with 10% increase in days fished per vessel.
3. Eliminate size restriction in Bay and Gulf waters.
4. Combine 1 and 3 above.
5. Combine 2 and 3.
6. Close the spring inshore season, May 15 - July 15.

the new equilibrium are shown in Table 8. Each policy will be discussed in term.

Management Alternative 1: Close Offshore June and July

The shrimp management plan suggests closing the FCZ in conjunction with the closure of Texas territorial waters for as many as 60 days during June and July. The Texas territorial waters usually are closed from June 1 to July 15. Thus, the analysis will examine a 60-day maximum closure under Management Alternative 1 and then look at a 45 days under Management Alternative 2.

Results for closing the offshore during the 60-day period of June and July are shown under Management Alternative 1 in Tables 7 and 8 and plotted in Figures 4 through 7. Yield curves for boats and vessels are shown in Figures 4 and 5, and cost and revenue curves are shown in Figures 6 and 7. In Figures 4 and 5, Point 1 represents the baseline equilibrium, Point 2 represents the situation one year after the policy change, and Point 3 represents the new equilibrium after the policy change.

The TFC curves in Figures 6 and 7 represent a long-run total factor cost, which includes variable cost, fixed cost and opportunity cost of labor and capital. A movement along the curve occurs by changing the days fished per craft and by holding the number of craft in the fleet constant. The total value of the product curves (TVP) represent the dollar value of the shrimp produced. As before, Point 1 represents the baseline equilibrium, the point at which no excesss profits are made (TVP = TFC). Point 3 represents the situation one year after the policy change. There is usually

Table 8. New Equilibrium Impact of Management Alternatives for Texas Shrimp Fishery.

Item or Group Affected	Management Alternatives[1]							
	1	1a	2	2a	3	4	5	6
1. Change in days fished								
Boats	-1,428	-1,628	-968	-1,197	-265	-1,542	-1,111	-5,831
Vessels	-10,567	-3,057	-6,121	-1,225	12,311	-1,448	-3,912	4,193
2. Change in landings								
Boats (mil lbs)	-0.52	-0.61	-0.34	-0.44	-0.11	-0.56	-0.39	-2.50
Vessels (mil lbs)	-2.79	0.51	-1.04	1.90	11.99	6.39	9.00	2.65
Total effect on available supply (mil lbs)	-3.31	0.10	-1.38	1.46	11.88	5.83	8.61	0.15
3. Change in estimated culls								
Boats (mil lbs)	0.00	0.00	0.00	0.00	-0.02	-0.02	-0.02	0.00
Vessels (mil lbs)	-2.21	-1.49	-1.45	-0.70	-6.58	-6.58	-6.58	0.62
4. Change in No. Crafts								
Boats	-33	-40	-21	-29	-9	-37	-26	-106
Vessels	22	107	44	108	273	280	306	92

1) 1. Close Texas offshore June and July.
1a. Close Texas offshore June and July with 10% increase in days fished per vessel during rest of year.
2. Close Texas offshore June and first two weeks in July.
2a. Close Texas offshore June and first two weeks in July with 10% increase in days fished per vessel.
3. Eliminate size restriction in Bay and Gulf waters.
4. Combine 1 and 3 above.
5. Combine 2 and 3.
6. Close the spring inshore season, May 15 - July 15.

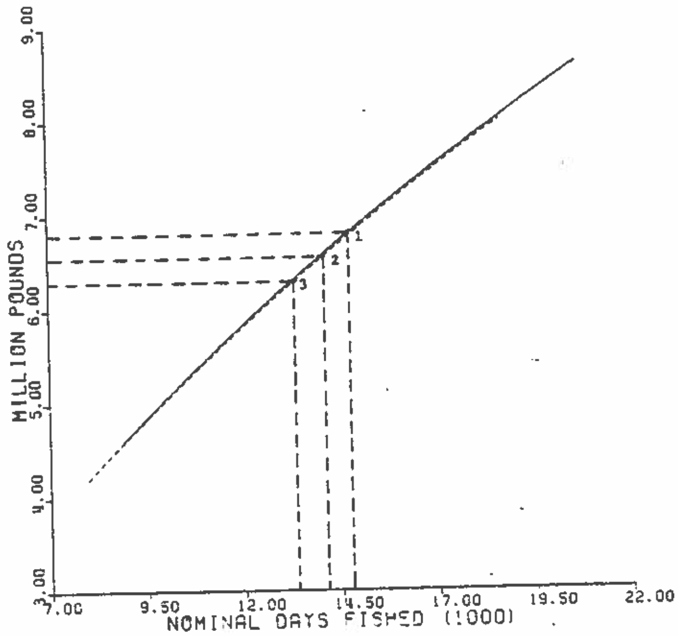

Figure 4. Yield curves of boats for baseline (solid line) and for closing the Texas offshore June and July (dashed lines).

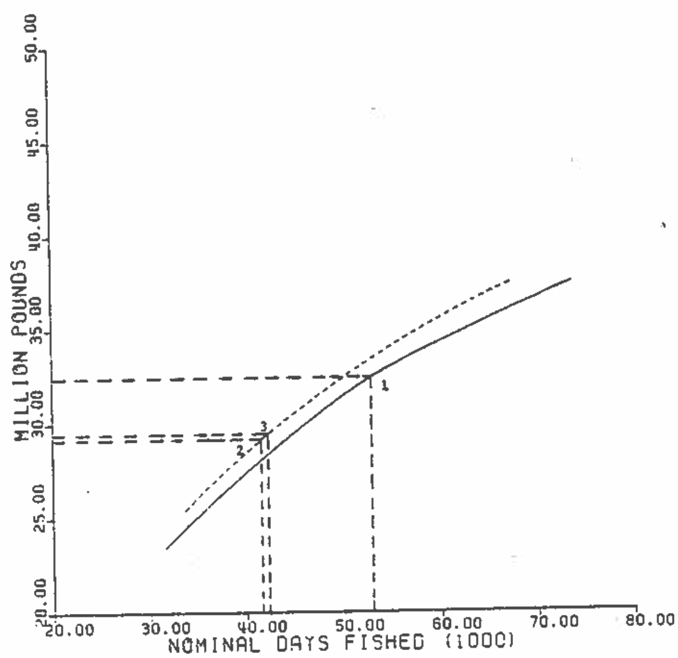

Figure 5. Yield curves of vessels for baseline (solid line) and for closing the Texas offshore June and July (dashed lines).

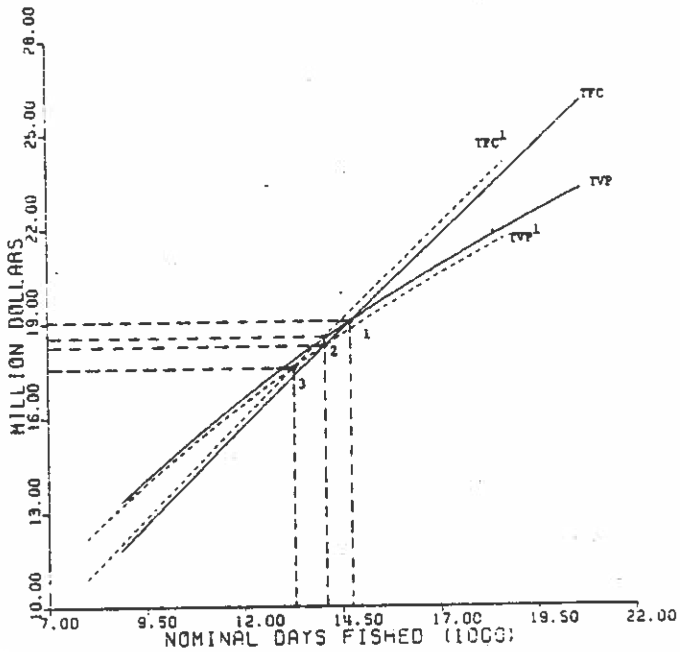

Figure 6. Total value product and total factor cost curves of boats for baseline (solid lines) and for closing the Texas offshore June and July (dashed lines).

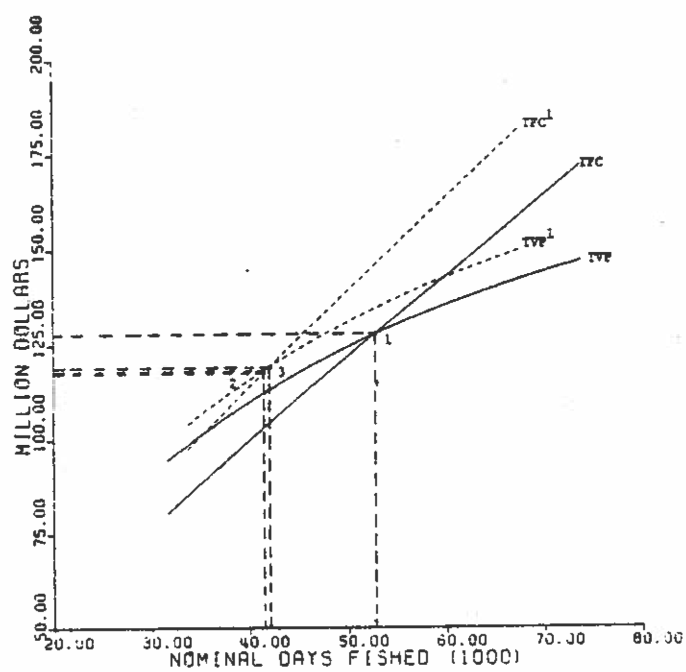

Figure 7. Total value product and total factor cost curves of vessels for baseline (solid lines) and for closing the Texas offshore June and July (dashed lines).

a Point 2 on the dashed TFC^1 curve and Point 2 on the dashed TVP^1 curve because the industry is in disequilibrium, and either excess profits are being captured or losses are being incurred. From disequilibrium (point 2), the industry will begin to move toward point 3 along the dashed lines toward the new equilibrium. At point 3 excess profits are again zero.

Closing the offshore reduces days fished for bay boats and Gulf vessels by 488 and 11,351, respectively, during the first year the policy is in effect; the number of boats and vessels are constant (Table 7, Figure 4 and 5). This is a reduction of 3.3. percent for bay boats and 21.6 percent for Gulf vessels. During the first year, landings of bay boats were reduced by 0.18 million pounds and those of Gulf vessels by 3.28 million pounds, reducing available supplies for the first year the policy is in effect by a total of 3.46 million pounds.

The reason for the reduction is seen in Table 9. Monthly offshore landings are shown for brown and white shrimp under the baseline and Management Alternative 1 conditions (for the first year). By closing the offshore fishery during June and July, 6.7 million pounds of brown shrimp and 0.66 million pounds of white shrimp are not landed during these two months. Landings of brown shrimp during August-December increase by more than 20 percent, from 17.09 to 20.74 million pounds. An increase of 35 percent would be required during this period, however, to make up the loss due to closure. As shown in Figure 5, the shift up in the yield curve for Gulf vessels does not offset reduction in landings caused by reducing days fished.

The main gain from closing the offshore is to help reduce the shrimp lost due to culling. Culls are reduced by 2.29 million pounds (Table 7, but compared to estimated current levels of culling (Table 6) the practice is far from eliminated.

Table 9. Comparison of Estimated Offshore Landings for Baseline and Closing Texas Offshore June and July (First Year Landings).

	Brown			White		
	Baseline	Policy 1	Change	Baseline	Policy 1	Change
Jan.	0.67	0.71	0.04	0.12	0.12	0.00
Feb.	0.47	0.50	0.03	0.17	0.69	0.00
Mar.	0.48	0.50	0.02	0.24	0.24	0.00
Apr.	0.47	0.49	0.02	0.20	0.20	0.00
May	0.84	0.84	0.00	0.39	0.39	0.00
Jun.	1.95	0	-1.95	0.32	0	-0.32
Jul.	4.75	0	-4.75	0.34	0	-0.34
Aug.	7.04	9.17	2.13	0.15	0.16	0.01
Sep.	4.01	4.84	0.83	0.66	0.71	0.05
Oct.	2.84	3.24	0.40	1.46	1.53	0.07
Nov.	1.99	2.19	0.20	1.62	1.66	0.04
Dec.	1.21	1.30	0.10	0.29	0.29	0.00
Tot	26.73	23.77	-2.96	5.95	5.47	-0.48
Aug-Dec	17.09	20.74	21.1%	4.18	4.35	4.8%

As expected, excess profits to Gulf vessel owners increased by $2.29 million (Table 7). However, Gulf vessel crews lost $2.01 million. Their excess profit decreases because they are idle two months, and increased revenues during the rest of the year do not compensate for the revenue lost in June and July. This circumstance would make it more difficult to maintain good crews year around. In this analysis it is assumed that both, bay boats and Gulf vessels are owner-operated and that the crew gets 20 percent of the revenue. For an owner/operator to maintain a good crew it is assumed that he will absorb any losses incurred by the crew as a result of a policy change so that excess profit to the crew is at least zero. Thus, excess profit to the vessel owners under this assumption is actually $0.28 million ($2.29 - $2.01 = $0.28). During the first year under Management Alternative 1, bay boat owners lost $0.40 million ($0.28 + $0.12 = $0.40). This assumes that bay boats will not redirect any of the effort they expend in the offshore area to the inshore area.

Figures 6 and 7 show the disequilibrium position as the Point 2's for boats and vessels, respectively. The industry will now adjust toward the new equilibrium, Point 3. Bay boats will begin to move out of the industry, reducing days fished because they are incurring losses (Figure 6), and Gulf vessels will move into the industry, increasing days fished because they are making excess profits (Figure 7). Once the new equilibrium is reached, 33 full-time-equivalent bay boats will have left the industry, and 22 full-time-equivalent Gulf vessels entered (Table 8). Excess profits will then be zero for owners and crews. There are 3.31 million pounds less shrimp available for consumption annually, and shrimp culling is reduced by one-third.

The above analysis assumes that Gulf vessels hold their fishing activities constant during the 10 months the fishery is open. However, it seems reasonable to assume that they will increase their fishing activity during the 10-month period, because the 2-month closure allows for vessel maintenance. The analysis was re-evaluated under the assumption that vessels would increase by 10 percent their days fished during these 10 months. The results are shown as Management Alternative 1a in Tables 7 and 8. The results are somewhat different from those when effort per vessel was constant for the 10-month period. Under the new equilibrium, an additional 107 full-time-equivalent Gulf vessels enter the industry, and total available supplies are essentially unchanged from the baseline. Culls are decreased only by 1.49 million pounds.

Management Alternative 2: Close Offshore July and First Two Weeks of July

Closing the offshore for 60 days during June and July causes a substantial loss of landings that are not made up after closure. To better approximate the effects of a 45-day closure, the analysis was run so that the season is closed for June and only the first two weeks of July. The results are different for Gulf vessel owners, but for bay boats they are essentially the same as under Management Alternative 1. Gulf vessel landings decrease 1.86 million pounds instead of 3.46 million pounds. Excess profits for the first year are $1.12 million greater, assuming owners absorb crew's losses (Table 7). Under the new equilibrium, available supply is reduced by less than one-half the reduction caused by Management Alternative 1 (Table 8). The number of full-time-equivalent Gulf vessels entering is 44, twice the number under Management Alternative 1. Culls are reduced by only 1.45 million pounds.

Results of re-evaluating the analysis under the assumption that vessels will increase their effort by 10 percent per vessel are shown under Management Alternative 2a in Tables 7 and 8. The results are similar to Management Alternative 1a except for culls and landings of vessels. Consumers gain an additional 1.46 million pounds of shrimp under the new equilibrium, and culls decrease by only 0.70 million pounds.

Management Alternative 3: Eliminate Size Restriction Inshore and Offshore

Baxter (1973) gives two reasons besides the size restriction why small shrimp are discarded: (1) "box-grading of shrimp by processors encourages discarding of smaller shrimp at sea and (2) the vessel crews are often unable to 'head' the entire catch at sea, so they concentrate on the larger shrimp which bring the best price and they discard the smaller ones of lesser value". Recognizing these problems it is assumed for this analysis that vessels can land all their catch with their current equipment and labor.

During the first year under this Management Alternative the number of days fished remain constant (Table 7). Landings increase the first year by the same amount that culls decrease. There is little effect on bay boats because (1) there is currently no size restriction May 15 to July 15 and November 1 through December, (2) the count law has been changed from 39 to 50 heads-on from August 15 to October 31, and (3) it is assumed boats land

90 percent of the undersized shrimp during August 15 to October 31.

Vessel landings increase by 6.58 million pounds (20 percent) and consumers now enjoy 6.6 million more pounds of shrimp. Excess profits for the first year are $9.78 million for vessel owners and $2.44 million for vessel crews.

To reach the new equilibrium (Point 3 from Point 2 in Figure 8) 273 full-time-equivalent Gulf vessels will move into the industry, increasing fishing for shrimp by 12,311 days. Nine bay boats leave the industry because of the added fishing pressure by vessels in the offshore area (Table 8). Gulf vessels land an additional 11.99 million pounds annually, and available supplies increase by 11.88 million pounds.

Prices of shrimp are held constant in this analysis. In reality, however, an increase in quantity of small shrimp on the market could possibly cause the price of shrimp, especially small ones, to decrease. If the price decreased, new equilibrium would be somewhere to the left of Point 3 in Figure 8.

In Management Alternative 3 it is assumed that the state of Texas would continue to close the territorial sea. However, with the ability to land any size shrimp in Texas this might encourage illegal harvesting of small brown shrimp in the territorial sea. Possibly the only way to maintain a fishery that harvests predominant large shrimp would be to close the territorial sea and FCZ and eliminating the size restriction on landings. Management Alternatives 4 and 5 consider this combination.

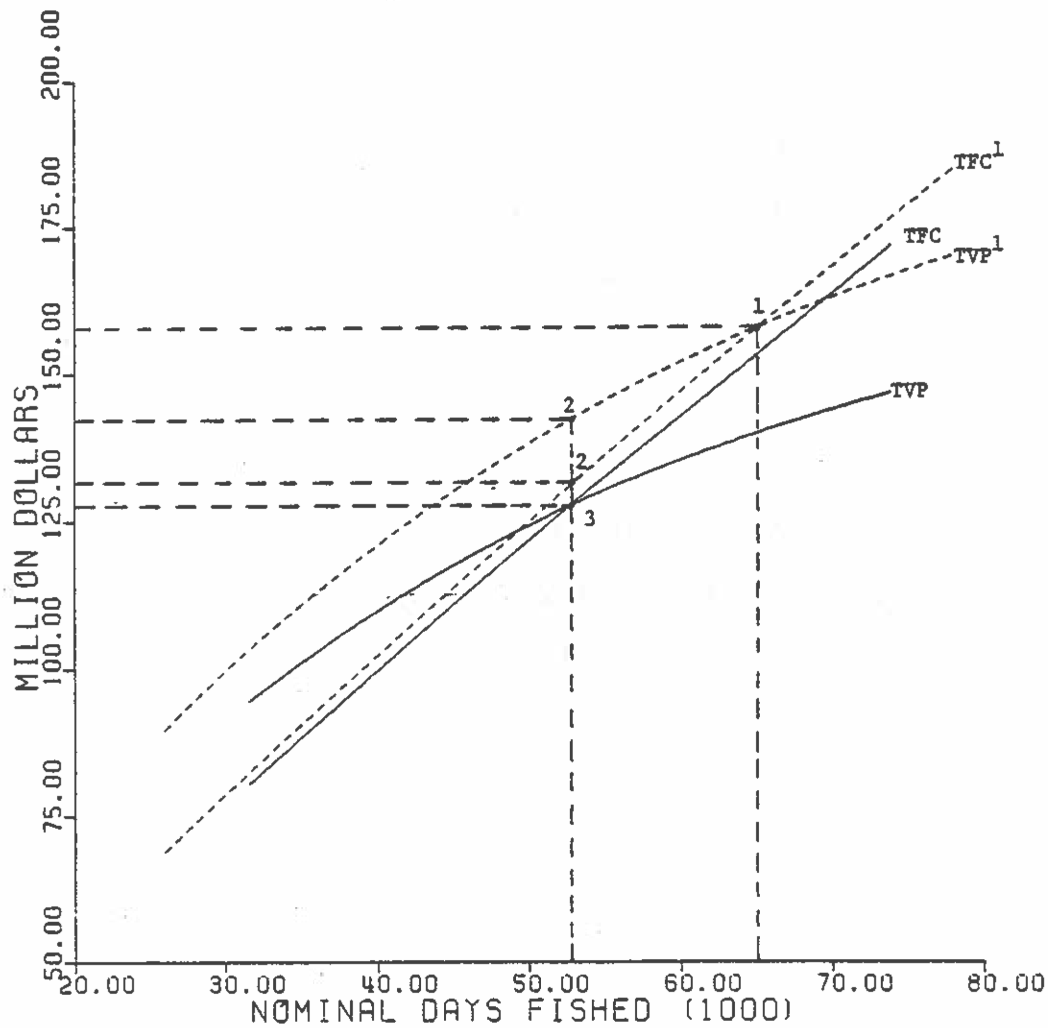

Figure 8. Total value product and total factor cost curves of vessels for baseline (solid lines) and for a Texas no Count Law (dashed lines).

Management Alternative 4: Close Offshore June and July and Eliminate Size Restriction

In the first year bay boat landings decrease 0.16 million pounds and Gulf vessel landings increase 1.01 million pounds (Table 6). Bay boat owners lose $0.24 million, and Gulf vessel owners capture excess profits of $8.83 million ($9.14 - $0.31). Both bay boat and Gulf vessel crews incur a slight loss. Under the new equilibrium, 5.83 million more pounds of shrimp are available for consumption (Table 8). Thirty-seven full-time-equivalent bay boats leave the industry, and 280 additional Gulf vessels enter. When compared to the two management measures individually (alternatives 1 and 3), the two policies partially offset each other. The closure offsets some of the short-run gains to Gulf vessels that result from eliminating size restrictions.

Management Alternative 5: Close Offshore June and Two Weeks of July and Eliminate Size Restriction

Under this alternative, available supply increases by three million pounds in the short run and by 8.61 million pounds once the new equilibrium is reached and discarding is eliminated (Table 7). Excess profits in the short run are $10.28 million and $0.78 million to Gulf vessel owners and crew, respectively. There is a small loss to bay boat owners and crew. At the new equilibrium, an estimated 26 full-time bay boats leave the industry and 306 full-time Gulf vessels will enter (Table 8).

Management Alternative 6: Close Inshore, May 15 - July 15

This Management Alternative addresses an issue of great concern to bay boat and Gulf vessel and one that historically has been a source of conflict between the two groups. Closing the inshore makes the brown shrimp inaccessible to bay boat owners because they cannot trawl the deeper waters offshore. During the first year, closing the inshore causes days fished by boats to decrease by 3,436 days, with essentially no change in Gulf vessel fishing activity because they do not fish inshore waters. Bay boat landings decrease by 1.66 million pounds, and Gulf vessel landings increase by 0.89 million pounds. A decrease in available supplies of 0.87 million pounds is incurred the first year. Excess profits to Gulf vessels owners increase by \$2.68 million, and to vessel crews by \$0.66 million (Table 7). Bay boat owners incur a loss of \$1.22 million ($0.69 \pm 0.53 = 1.22$).

Under the new equilibrium (Table 8), 106 full-time-equivalent bay boats leave the Texas industry, and 92 Gulf vessels enter. The decline in bay boat landings are slightly more than offset by the added Gulf vessel landings. In terms of impact on small brown shrimp, during May, June and July bay boats landed 1.16 million pounds of small brown shrimp (cull-size shrimp for Gulf vessels). By closing the inshore area during May, June and July this 1.16 million pounds will be allowed to move offshore. GBFSM estimates that Gulf vessels will catch an additional 0.62 million pounds of culls for a total of 7.2 million pounds of culls. This is a net reduction of only 0.54 million pounds of small shrimp traditionally landed by bay boats.

Present Value Analysis

Implementing any of the six suggested policies will upset the equilibrium of the Texas shrimp industry. It will move from disequilibrium toward a new equilibrium. The number of fishing craft will increase in those user groups capturing excess profits until excess profits are zero again. Conversely, user groups incurring a loss will have fishing craft move out of their fleet until equilibrium is reached. The magnitude of real profit (or loss) to user groups is the annual stream of profits (or losses) over that period of time until the new equilibrium is reached. Table 10 shows the present value of the stream of profits or losses for alternative adjustment periods assuming a three percent real discount rate. Adjustment is assumed to take place in equal increments of excess profit reduction (or loss reduction) each year until equilibrium is reestrablished.

In every policy considered there, Gulf vessels captured excess profits. In every case losses were incurred by bay boats, except in Management Alternative 3, for which the effect is unknown because they go from a very small positive effect to a very small negative effect.

Table 10 shows that when closing the offshore during June and July and assuming Gulf vessels maintain a constant level of days fished per vessel, the stream of excess profits will range from $0.53 to $0.78 million depending on how long it takes to establish a new equilibrium. Depending on this time, this measure will cost bay boat owners $1.63 to $2.27 million. However, if Gulf vessels increase their effort by 10 percent during the 10 months the offshore is open, this present value stream of excess profits increases to a range of $6.86 to $10.09 million. When comparing the offshore closure for two months vs. 1.5 months, the latter is least costly

Table 10. Present Value of Stream of Excess Profits (Losses) in Million Dollars for Suggested Policies on Owner/Operator of Fishing Craft Using a Three Percent Real Discount Rate.

Policy	Boats		Vessels	
	8 Years	12 Years	3 Years	5 Years
1. Close Offshore June and July	-1.63	-2.27	0.53	0.78
1a. Close Offshore June and July + 10%	-1.84	-2.56	6.86	10.09
2. Close Offshore June and Two Weeks July	-0.98	-1.36	2.67	3.92
2a. Close Offshore June and Two Weeks July +10%	-1.23	-1.70	7.64	11.24
(Crew)			(0.48)	(0.70)
3. No Count Law	insign.	insign.	18.62	27.40
(Crew)			(4.65)	(6.84)
4. Combination 1 and 3	-1.43	-1.99	16.82	24.74
5. Combination 2 and 3	-0.78	-1.08	19.58	28.80
(Crew)			(1.49)	(2.19)
6. Close Inshore	-4.98	-6.93	5.10	7.51
(Crew)			(1.26)	(1.85)

to bay boats and has a greater present value for Gulf vessels.

If small shrimp that are presently culled can be landed with present equipment and labor, the present value of excess profits to Gulf vessel owners would range from $18.62 to $27.4 million and to their crews between $4.65 and $6.84 million. Under the assumption of constant prices the policy has almost no effect on bay boats. The combined offshore closures and the no count law (Management Alternative 4 and 5) has a large positive effect on Gulf vessels and a negative impact on bay boats. Under Management Alternative 6 the gain to Gulf vessel owners is achieved at a very large loss to bay boat owners.

Welfare Implications

The analysis of policy alternatives has shown that several policies appear to offer substantial net gains in producers' surplus to society. How should these fishery management alternatives be evaluated? Public policy decisions that stimulate a reallocation of society's resources often involve difficult judgements relative to their welfare implications. The role of welfare economics is to provide a decision framework for public policy based on evaluation of the social desirability of alternate economic states.

The Kaldor criterion is often the basis for public decision making. It holds that a move from allocation A to allocation B is socially preferable if those who gain from the move could compensate the losers (i.e., bribe those made worse off into accepting B) and still be better off than at A.

Consider some shrimp management alternative "B" that would reduce bay fishing effort and harvest and would produce a proportionately larger increase in Gulf harvest, relative to existing conditions under fishery management plan "A" (Figure 9). Assume prices are stable and can be represented by some composite shrimp price P_0. (The use of this horizontal price line instead of the conventional downward sloping demand curve further simplifies the analysis by eliminating the need to consider consumers' surplus, which is not a part of this analysis, in a quantititative sense.)

Contributions to shrimp supply under "A" are represented by S_b and S_g for the bay and Gulf sectors. S_t represents total supply. For alternative "B" these relationships are represented by SB_b, SB_g and SB_t, respectively. Clearly, the move to "B" results in a loss equal to area "X" for the bay shrimp sector, and a gain of "Y" to Gulf shrimpers. Since we expect "Y" to be a greater than "X", total supply will expand to SB_t. Hence, not only does the Gulf sector receive a larger amount of the producers' surplues, but the surplus is now larger (by an amount equivalent to the area "Z").

Clearly, a move from "A" to "B" is socially preferable under the Kaldor criterion (assuming that all relevant costs are reflected in the graph), because the gainers could compensate the losers and still obtain a net gain of "Z" in producers' surplus. This situation is representative of all policies analyzed.

On the basis of this analysis alone, the decision to adopt a management plan such as "B" in the Figure 9 discussion cannot be made. From a macro-economic viewpoint, not all relevant costs and benefits are being considered. The decision criteria of welfare economics are being applied

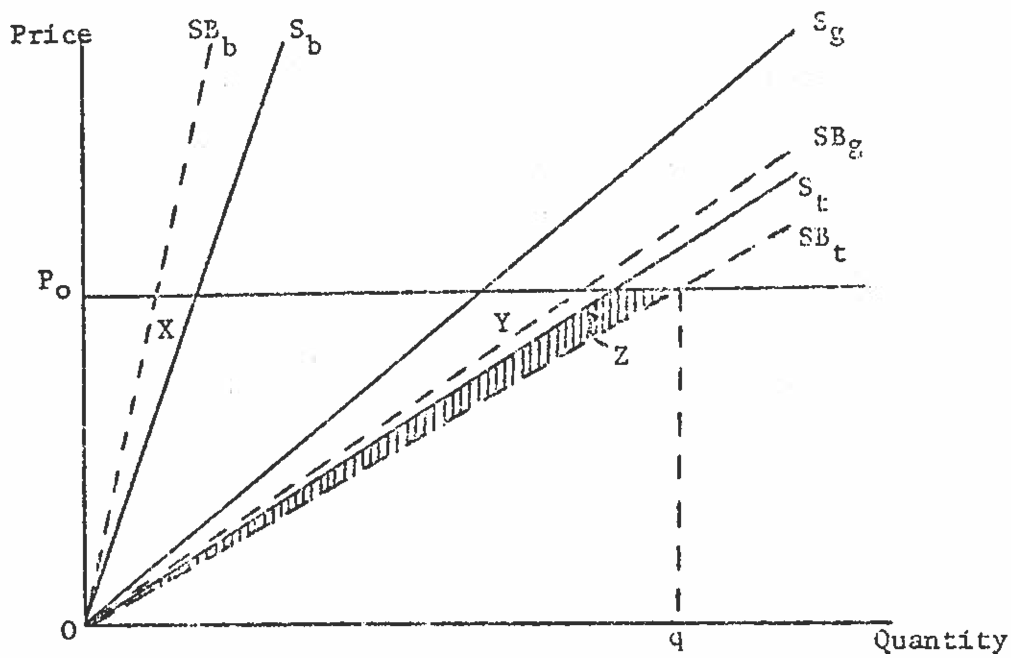

Figure 9. Hypothetical Change in Producers' Surplus Resulting from Restrictions in Bay Shrimping Effort, Price Fixed.

to financial costs and returns to primary producers only (excluding crew members), without an accounting of the social costs (and/or benefits) associated with disturbances in traditional fishing patterns.

The quantification of social costs is outside the scope of this research. Hence, the analysis of selected management alternatives on the basis of welfare economics must remain at a somewhat superficial level. There are, however, useful applications for the analysis, even without extensive socio-economic data.

For the bay boat or Gulf vessel owner, the results in terms of the effects on costs and returns to the individual bay and Gulf fleets are meaningful. Although individual owners are not likely to command effective power in the decision-making process, they can make their preferences known to policy makers. Estimated financial results presented for the various alternatives should provide owners with a basis for developing their expectations relative to possible effects of potential policies on their own operations, and for ranking their choices.

Results are also useful to planners in providing estimates of direct economic effects of several management alternatives on fishermen and fishing fleets. The indirect and socio economic effects are not identified, and should receive attention as part of any plan to alter substantially the existing shrimp management environment. However, the analyses presented here are relevant to socio economic considerations. For example, in a situation such as that represented in Figure 9, it may be concluded that if an analysis of relevant social costs and returns implies a reduction in net social benefits of less than the amount represented by "Z", then the move to the management alternative still represents a socially preferable act.

A Note on Prices

Throughout the preceding analysis of shrimp management alternatives a key assumption has been that shrimp prices remain fixed (though specified by size, species and time period through the simulation year). One rationale for this assumption is that changes in Texas shrimp landings precipitated by the management alternatives being analyzed are expected to be small relative to the overall supply of shrimp, so that effects of increased or reduced Texas landings would have a minimal effect on prices. This rationale allows a simplification of the model in that prices are considered "given".

Current research on Gulf shrimp prices by Chui (1980) may support the rationale for fixed pricing in a simulation model. Chui developed a set of demand equations that can be used to estimate the ex-vessel price of shrimp in the Gulf. These equations indicate that coefficients for shrimp landings and, in general, the t-values of significance of these coefficients, are smaller than those for other variables important in determining shrimp prices (i.e., price index for meat, fish and poultry; per capita expenditures in restaurants; shrimp imports; and existing shrimp stocks).

Limitation of the Analysis

Besides the underlying assumptions relating to the analyses and prices, as described previously, several limitations, primarily data limitations, affect the model. For example, wide ranges were discovered in the literature for natural mortality, and data relative to shrimp movement, abundance and susceptibility to harvest are very limited or nonexistent. Improvements in the biological data base should be encouraged as a direction for future research.

In the area of economics, a serious issue may be that of unreported catch, among bay boats in particular. Depending on the source, bay boat operators are reputed to catch and sell on a cash basis from zero to 100 percent more shrimp than they report. With such a wide range of unconfirmed increments to reported landings, it is impossible to adjust a simulation model to account for this phenomenon. Hence, the model is tuned to reported landings, but the reader is reminded that actual bay landings may be greater than reported.

Another limitation related to the contention that the average relative fishing power exerted upon the fishery in an average nominal day fished probably has increased in recent years as average vessel size and power have increased (Warren and Griffin, 1978). This phenomenon is not accounted for in the model, and its probable impact on the present results is that predicted effort levels at which decreasing landings can be expected are probably overestimated, because an average day fished in 1980 undoubtedly exerts more pressure on the fishery than an average day fished in the 1963-1974 period.

CONCLUSIONS

This analysis has only considered the impact on owners of fishing craft, crew and consumer consumption. It has not considered the impact on shore facilities, processing and marketing sectors, fishing communities, recreational and bait fisherman, neighboring states and enforcement, which are all important considerations. The goal of the Gulf Council is to manage the shrimp fishery to "attain the greatest overall benefit to the nation with particular reference to food production and recreational opportunities on the basis of maximum sustainable yield as modified by relevant economic, social or ecological factor" (Center for Wetland Resources date). However, this goal is difficult to measure. Therefore, the policies have been discussed relative to these questions: Are landings increased? Are discards reduced? What user groups gain and what user groups lose? What happens to capital investment in Texas waters? This analysis has estimated answers to these questions.

The only policies that increase landings in the short run are those associated with no count law, Management Alternatives 3, 4 and 5. In the long run, when the new equilibrium is established, these three Management Alternatives still rank far better than the others, and for Management Alternatives 1, 2 and 6 landings decline.

Culls are eliminated (assuming vessels can and will land and their ' catch) under Management Alternatives 3, 4 and 5. Culls are reduced as little as one percent for Management Alternative 6 and 34 percent for Management Alternative 1. Culls actually increase one percent for Management Alternative 6.

Among the two user groups, Gulf vessel owners benefit in that those in the industry when the management alternative is enacted reap a windfall gain in present value of the stream of excess profits until the new equilibrium is reached. Conversely, in every management alternative bay boats experience a windfall loss in present value of the stream of excess losses until the new equilibrium is reached. Gulf vessels gain the most from Management Alternatives 3, 4 and 5, and bay boats lose the most from Management Alternative 6. When closing the offshore area, bay boats will most likely transfer some of their effort exerted offshore to the inshore area when possible. Therefore, for Management Alternatives 1 through 5 the estimated losses for bay boats are probably an upper limit. Likewise, redirecting the effort inshore by bay boats will slightly affect offshore landings such that the gains offshore are probably slightly overestimated. Gulf vessel crews benefit only under Management Alternatives 2a, 3, 5 and 6.

In all the management alternatives analyzed bay boats leave the Texas industry and Gulf vessel enter. Under assumptions of an open-access, common property resource, a situation that generates profit cannot be maintained. Additional Gulf vessels will move into an industry that is already perceived to be able to harvest the shrimp resource in Texas waters. Management Alternatives 3, 4 and 5, for which excess profits are estimated to be the greatest, will entice the most Gulf vessels into the industry, approximately 25 percent more. Without some mechanism for protecting these profits, such as limited entry or by taxing them, the industry will become more crowded.

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APPENDIX A

Table 1a. Natural Mortality Rate per Week Heads-on Count/Pound.

Mortality Level	Greater than 40 Count	31 to 39 Count	19 to 30 Count	13 to 18 Count	Less than 12 Count
			Brown		
Low	.08	.08	.08	.08	.08
Med-Low	.12	.11	.09	.07	.07
Med-High	.16	.12	.09	.08	.08
High	.20	.15	.11	.08	.07
			White		
Low	.08	.08	.08	.08	.08
Med-Low	.12	.11	.10	.09	.09
Med-High	.16	.14	.12	.10	.10
High	.20	.16	.13	.10	.09

Table 2a. First-Year Impact Closing Offshore June and First Two Weeks July for Texas Shrimp Fishery.

Item or Group Affected	Natural Mortality 0.20	0.16	0.12	0.08
1. Change in Days Fished				
Boats	-364	-364	-364	-364
Vessels	-7,823	-7,823	-7,823	-7,823
2. Change in Landings				
Boats (Mil lbs)	-0.12	-0.12	-0.11	-0.12
Vessels (Mil lbs)	-2.10	-1.86	-2.79	-2.16
Consumers (Mil lbs)	-2.22	-1.98	-2.90	-2.28
3. Change in Estimated Culls				
Boats (Mil lbs)	0.00	0.00	0.00	0.00
Vessels (Mil lbs)	-1.95	-1.63	-1.45	-1.18
4. Change in Excess Profits				
Boats Owners (Mil $)	-0.16	-0.16	-0.17	-0.21
Vessel Owners (Mil $)	1.92	2.55	2.52	1.20
Boat Crew (Mil $)	-0.08	-0.08	-0.08	-0.09
Vessel Crew (Mil $)	-1.31	-1.15	-1.16	-1.49

Table 3a. First-Year Impact of Closing Offshore June and First Two Weeks July with Ten Percent Decrease in Days Fished Per Vessel.

Item or Group Affected	Natural Mortality			
	0.20	0.16	0.12	0.08
1. Change in Days Fished				
Boats	-364	-364	-364	-364
Vessels	-3,344	-3,344	-3,344	-3,344
2. Change in Landings				
Boats (Mil lbs)	-0.13	-0.13	-0.13	-0.13
Vessels (Mil lbs)	-0.16	0.02	0.04	-0.14
Consumers (Mil lbs)	-0.29	-0.11	-0.09	-0.27
3. Change in Estimated Culls				
Boats (Mil lbs)	0.00	0.00	0.00	0.00
Vessels (Mil lbs)	-1.41	-1.17	-1.04	-0.85
4. Change in Excess Profits				
Boats Owners (Mil $)	-0.20	-0.21	-0.22	-0.25
Vessel Owners (Mil $)	3.55	4.01	3.96	3.41
Boat Crew (Mil $)	-0.09	-0.09	-0.09	-0.10
Vessel Crew (Mil $)	0.12	0.25	0.23	0.87

Table 4a. First-Year Impact of Closing Offshore June and First Two Weeks July and Nov Count Law.

Item or Group Affected	Natural Mortality 0.20	0.16	0.12	0.08
1. Change in Days Fished				
Boats	-364	-364	-364	-364
Vessels	-7,823	-7,823	-7,823	-7,823
2. Change in Landings				
Boats (Mil lbs)	-0.10	-0.10	-0.09	-.09
Vessels (Mil lbs)	3.77	3.10	2.65	1.41
Consumers (Mil lbs)	3.67	3.00	2.56	1.32
3. Change in Estimated Culls				
Boats (Mil lbs)	-0.02	-0.02	-0.02	-0.02
Vessels (Mil lbs)	-7.80	-6.58	5.89	4.76
4. Change in Excess Profits				
Boats Owners (Mil $)	-0.11	-0.12	-0.14	-0.17
Vessel Owners (Mil $)	10.98	10.28	9.51	6.90
Boat Crew (Mil $)	-0.07	-0.07	-0.72	-0.08
Vessel Crew (Mil $)	-0.96	-0.78	0.59	-0.06

Table 5a. First-Year Impact of Closing Inshore During Spring Season.

Item or Group Affected	Natural Mortality			
	0.20	0.16	0.12	0.08
1. Change in Days Fished				
Boats	-3,436	-3,436	-3,436	-3,436
Vessels	-15	-15	-15	-15
2. Change in Landings				
Boats (Mil lbs)	-1.63	-1.66	-1.67	-1.67
Vessels (Mil lbs)	-0.66	0.89	1.06	1.07
Consumers (Mil lbs)	-0.98	-0.87	0.61	-0.60
3. Change in Estimated Culls				
Boats (Mil lbs)	0.00	0.00	0.00	0.00
Vessels (Mil lbs)	0.10	0.12	0.13	0.11
4. Change in Excess Profits				
Boats Owners (Mil \$)	-0.59	-0.69	-0.72	-0.80
Vessel Owners (Mil \$)	2.00	2.68	3.22	3.31
Boat Crew (Mil \$)	-0.51	-0.53	-0.54	-0.56
Vessel Crew (Mil \$)	0.50	0.66	0.80	0.82

A P P E N D I X B

Table 1b. Baseline Days Fished for Boats and Vessels by Species, Inshore-Offshore and Month, 1970-1974 Average.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Total
Boats													
Brown													
Inshore	0	0	0	17	387	987	434	257	172	13	0	2	2,269
Offshore	12	7	7	9	12	37	109	118	27	16	16	15	385
White													
Inshore	18	48	79	392	1,086	366	128	1,973	2,989	2,982	871	203	11,135
Offshore	14	25	31	81	134	169	161	19	69	129	57	16	905
Total	44	80	117	499	1,619	1,559	832	2,367	3,257	3,140	944	236	14,694
Vessels													
Browns													
Inshore	0	0	0	0	0	10	0	0	0	0	0	0	10
Offshore	1,361	1,119	1,081	1,449	2,188	3,105	7,030	8,267	6,246	4,454	2,656	2,201	41,157
White													
Inshore	0	0	0	0	0	3	0	0	0	65	0	0	68
Offshore	238	444	740	968	1,685	613	608	181	882	2,027	2,122	509	11,017
Total	1,599	1,563	1,821	2,417	3,873	3,731	7,638	8,448	7,128	6,546	4,778	2,710	52,252

Table 2b. Baseline Estimated Catch in Million Pounds Inshore of Brown Shrimp by Size Class and Month.

	COUNT					
Month	Under-20	21-30	31-50	51-67	68-Over	Culls
Jan	0	0	0	0	0	0
Feb	0	0	0	0	0	0
Mar	0	0	0	0	0	0
Apr	0	0	0	0	0.01	0
May	0	0	*	0.01	0.15	0
Jun	0	0	0.02	0.04	0.56	0
Jul	0	0	0.02	0.02	0.24	0
Aug	0	0	0.01	0.01	0.10	0.01
Sept	0	0	*	*	0.03	*
Oct	0	0	0	0	*	0
Nov	0	0	0	0	0.01	0
Dec.	0	0	0	0	0	0
Tot	0	0	0.05	0.98	1.10	0.01

Asterisk (*) implies landings between 1,000 and 4,999 pounds.
Pounds less than 1,000 entered as zero.

Table 3b. Baseline Estimated Catch in Million Pounds Offshore of Brown Shrimp by Size Class and Month.

Month	COUNT Under-20	21-30	31-50	51-67	68-Over	Culls
Jan	0.14	0.27	0.14	0.01	*	0.03
Feb	0.12	0.18	0.08	0.01	*	0.02
Mar	0.16	0.16	0.06	0.01	*	0.05
Apr	0.18	0.31	0.09	0.03	0.01	0.14
May	0.24	0.14	0.03	0.07	0.02	0.30
Jun	0.34	0.32	0.91	0.20	0.06	0.86
Jul	0.45	1.14	2.79	0.47	0.10	1.42
Aug	0.40	2.28	3.75	0.49	0.11	1.67
Sep	0.26	1.82	1.86	0.28	0.05	0.96
Oct	0.23	1.30	1.26	0.18	0.03	0.44
Nov	0.26	0.92	0.76	0.08	0.01	0.23
Dec	0.25	0.64	0.37	0.04	0.01	0.12
Tot	3.03	9.32	12.39	1.86	0.41	6.26

Asterisk (*) implies landings between 1,000 and 4,999 pounds.

Table 4b. Baseline Estimated Catch in Million Pounds Inshore of White Shrimp by Size Class and Month.

	COUNT					
Month	Under-20	21-30	31-50	51-67	68-Over	Culls
Jan	0	*	*	0	0	0
Feb	0	0	0	0	0	0
Mar	0	0	0	0	0	0
Apr	*	*	*	*	*	0
May	*	*	0.02	0.06	0.06	0
Jun	*	*	0.05	0.03	0.01	0
Jul	0	0.01	0.02	0.01	0.01	0
Aug	0.04	0.28	0.42	0.29	0.17	0.02
Sep	0.07	0.20	0.45	0.35	0.20	0.02
Oct	0.05	0.16	0.42	0.33	0.20	0.02
Nov	0.02	0.08	0.20	0.13	0.06	0.01
Dec	*	0.01	0.02	0.01	*	0
Tot	0.19	0.75	1.62	1.21	0.72	0.07

Asterisk (*) implies landings between 1,000 and 4,999 pounds.
Pounds less than 1,000 entered as zero.

Table 5b. Baseline Estimated Catch in Million Pounds Offshore of White Shrimp by Size Class and Month.

	COUNT					
Month	Under-20	21-30	31-50	51-67	68-Over	Culls
Jan	0.04	0.04	0.03	0.01	0	*
Feb	0.04	0.04	0.03	0.01	0	*
Mar	0.08	0.09	0.04	0.01	0	0.01
Apr	0.07	0.05	0.03	0.01	*	0.01
May	0.11	0.05	0.05	0.08	0.01	0.05
Jun	0.05	0.03	0.14	0.04	*	0.01
Jul	0.03	0.10	0.10	0.03	*	0.01
Aug	0.02	0.06	0.04	0.01	*	0.01
Sep	0.16	0.19	0.17	0.06	*	0.02
Oct	0.39	0.41	0.37	0.12	*	0.05
Nov	0.41	0.43	0.39	0.12	*	0.04
Dec	0.11	0.12	0.09	0.02	*	0.01
Tot	1.51	1.64	1.46	0.52	0.03	0.21

Asterisk (*) implies landings between 1,000 and 4,999 pounds.
Pounds less than 1,000 entered as zero.